Energy Efficient Data Transmission through Relay Nodes in Wireless Sensor Networks

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Abstract—**In a Wireless Sensor Network (WSN) having a single sink, information is given to the distant nodes from beacons by overhearing. Since it is out of the communication range, information is not sent directly to the static sink (SS). If a distant node is not able to communicate directly, then it should send its own packet to another node which is closer to the Base Station (BS) so that the received packets are relayed to the BS by this node. In this paper, we propose a relay node selection algorithm to reduce contention and improve energy efficiency. In this algorithm, each data packet of direct communication should include the received signal strength (RSS) of the beacon packet. The distant node selects a node with the maximum RSS value as a relay. The algorithm also assigns transmitting intervals to each relay node. By our simulation results, we show that our proposed algorithm improves the packet delivery ratio and energy efficiency.**

Index Terms—**Wireless Sensor Network (WSN), Data Transmission, Relay Nodes, Base Station(BS), received signal strength (RSS).**

I. Introduction

A large number of sensor nodes arranged in an area, which is incorporated to work together in a wireless medium is known as the wireless sensor network (WSN). Generally these small sized sensors can sense, process data, and communicate with each other through a radio channel. General engineering, agriculture and environmental monitoring, civil engineering, military applications and health monitoring are the applications of WSN. One of its applications is to collect data which is scattered in a region through its sensor nodes. Self-organization, multi-hop cooperative relay and large-scale dense deployment include WSN characteristics. Disadvantages of WSN include node energy, transmission power, memory, and computing power [1].

In sensor networks, the node around the sink gets depleted out of energy due to the continuous data forwarding to the single sink. To save the energy of these nodes additional node which are few hops from the sink are selected for the data transfer to the stationary sink. This condition increases the total transmission power, limits the sensor coverage in the network, thereby making the network inadequate. Due to inadequate motion potential, it is capable of relocating the sink close to a region of heavy traffic or close to the loaded nodes. This decreases the total transmission power which in turn extends the lifetime of the nodes on the path of profound traffic. The relocating sink can balance the traffic load in the middle of multiple nodes and thereby decrease the miss rate of real-time packets. This is favorable for real time applications. [2].

Sink deployment can be performed in the following ways.

(i). Multiple Sink Deployment

Since data is always sent to the closest sink, multiple sinks should be deployed. This will decrease the average number of hops a message has to pass through before being received and processed by a sink. [4]

(ii). Deploying Mobile Sink

WSN takes advantage of the mobility capacity when a sink moves fast to deliver data with a tolerable delay. Data from the nodes are collected and transported by the mobile sink with mechanical movements. The delay in the data delivery for the reduction of energy consumption of nodes is operated in this system. [5]

(iii). Deploying Multiple Mobile Sinks

It is possible to get the sensor data without delay and without causing buffer overflow by deploying multiple mobile sinks.

By introducing multiple sinks in the WSN, several problems can be avoided. Unexpected failures or intentional attacks which could stop the whole sensor nodes to transmit data can be avoided. Sink failure of the network is averted. This is done by placing multiple sinks which influences the tolerance of a network.

In the previous work [13], a Particle swarm optimization (PSO) based algorithm which includes two phases (clustering and scheduling) has been developed for sink repositioning. All nodes are categorized into several clusters based on their overflow time and location in the first phase. Multiple sinks are deployed with mobility in the second phase. Based on the PSO technique, the scheduling algorithm generates node movement schedules for the sink for scheduling the sink mobility within a single cluster. At last, global sink movement path is formed by combining the scheduling solutions of all the clusters. Also, there is a central static sink which can be used to directly send the data from the sensors, in case of any mobile sink failure. In this paper we propose to deploy special type of nodes called relay nodes to forward the data from the sensors to the central static sink, which will further

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increase the lifetime of the network.

A Relay Nodes

When the source node is not within direct communication range of the sink there is a need for the relay nodes. At the end of the receiving period, when the relay node receives any data packet in the receive state, the data packets are buffered and scheduled for possible transmissions. At first, relay node is uncharged and when fully charged it will transit into the receive state. For transmitting a packet at the end of the receiving period, the node first senses whether the channel is clear. Or else, node goes into charging state until it is fully charged. [6].

By using the intermediate relay nodes sensor data is routed to the static sink. Selecting the relay nodes depends upon the distances between them which should be equal to a characteristic distance. The total power needed for routing is minimized by this distance which is a constant and is a consideration of the optimal transmission range. So in order to get close to the characteristic distance, few nodes are left in between the successive relays [12]. To act as cluster heads and to form a connected topology for data transmission in the higher level, relay nodes are used. The relay nodes make the data packets to blend with sensor nodes in their clusters and by using wireless multihop paths the data packets are sent to the sink [7].

In the network of the relay nodes, every sensor node should be able to reach at least two relay nodes and at least two node-disjoint paths should be present between every pair of relay nodes for the placement of a minimum number of relay nodes. Depending upon this placement when one relay node fails, each sensor node covered by this relay node can switch to one of its backup relay nodes and the remaining relay nodes are still connected [7]. The following things should be considered while using relay nodes,

- Finding a good relay node,
- Finding a route to the relay node [8].
- In order to support the survivability of the network, two or more relay nodes should be within a sensor node's communication range [7].

II. Related Work

Branislav Kusy et al [8] have presented an algorithm for data delivery to mobile sinks in wireless sensor networks. Their algorithm is based on information potentials, which they extend to account for mobility. They showed that for local movement along edges in the communication graph, the information potentials can be adapted using a simple iterative distributed computation. Also they addressed the iterative computation problem by introducing the mobility graph, which encodes knowledge about likely mobility patterns within the network.

Satyajayant Misra et al [9] have studied the constrained versions of the relay node placement problem, where relay nodes can only be placed at a subset of candidate locations. In the connected relay node placement problem, they placed a minimum number of relay nodes to ensure the connectivity of the sensor nodes and the base stations. In the survivable relay node placement problem, they placed a minimum number of relay nodes to ensure the bi-connectivity of the sensor nodes and the base stations.

Feng Wang et al [10] have presented an in-depth study on the traffic aware relay node deployment problem. They developed optimal solutions for the simple case of one source node, both with single and multiple traffic flows. They showed that the general form of the deployment problem is difficult and the existing connectivity-guaranteed solutions cannot be directly applied. They also transformed the problem into a generalized version of the Euclidean Steiner Minimum Tree problem (ESMT). Their solution is in continuous space and yield fractional numbers of relay nodes, where simple rounding of the solution can lead to poor performance. Thus they developed algorithms for discrete relay node assignment, together with local adjustments that yield high-quality practical solutions.

Zhi Ang Eu et al [6] have optimized network performance by finding the optimal routing algorithm and relay node placement scheme for wireless sensor networks powered by ambient energy harvesting. They evaluated the performance of three different variants of geographic routing algorithms and consider two relay node placement schemes, viz. uniform string topology and a cluster string topology.

Karim G. Seddik and K. J. Ray Liu [11] have considered the problem of deploying relay nodes in wireless sensor networks. They assume, some sensor nodes will provide "less-informative" measurements to the fusion center about the state of nature. They considered relay nodes deployment in the sensor network instead of the less-informative sensor nodes to forward the measurements of the other nodes. This introduces a new tradeoff in the system design between the number of measurements sent to the fusion center and the reliability of the more-informative measurements, which is enhanced by deploying more relay nodes in the network.

III. Cluster Based Scheduling Algorithm

In our previous work, Multi Objective Sink Repositioning (MOSR) algorithm was designed to solve the Mobile Element Scheduling problem. It aims to schedule the visits of the mobile element to each sensor to avoid data loss due to sensor buffer overflow. With the MOSR algorithm, we first group all nodes into clusters, such that nodes in the same cluster have similar deadlines and are geographically close to each other. Then, to solve the scheduling problem of the mobile element within a single cluster, we use the PSO to reduce the buffer overflow or data loss of the sensor nodes. Finally, the schedules for individual groups are concatenated to form the entire schedule.

Let Cj , $j = 1 \dots N$, denote cluster j , where C is the total number of clusters. In MOSR, nodes are first partitioned into clusters in such a way that overflow times of the nodes in cluster Ci is smaller than those in Cj , for $j > i > 0$. Moreover, the range of overflow times for nodes in $Ci + 1$ is

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twice that of . This allows the nodes in Ci . to be visited twice more frequently than the nodes in $Ci+1$ during generation of the visit schedules. Then, each cluster again is partitioned into sub-clusters so that nodes in the same sub-cluster are geographically close to each other. These two level partitioning results in groups of nodes with similar deadlines and locations. Therefore, in each sub-cluster, node visits can be scheduled using a PSO and vehicle routing problem. [13]

Algorithm-1

1. Randomly initialize the whole swarm
2. For $(i = 0; i < size\ of\ swarm; i++)i$
3. Evaluate $f(x_i)$
4. While (termination criterion is not meet){
5. For $(i = 0; i < size\ of\ swarm; i++)$ {
6. if $f(x_i) > f(pbest_i))$

   $pbest_i = x_i$
7. if $f(x_i) > f(gbest_i))$

$gbest = x_i$

8. Update (x_i, v_i)
9. Evaluating $f(x_i)$
10. }
11. }

In line 3, $f(xi)$ is the fitness function to estimate the quality of solution. And the line 8 is the most important part of PSO.

The particles update as follow:

$$v_{id}^{k+1} = w^* v_{id}^k + c_1 rand()*(pbest_{id}^k - x_{id}^k) + c_2 rand()*(gbest_d^k - x_{id}^k) \quad (1)$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \quad (2)$$

A . Clustering According to Overflow Times

Let $\min_{otime}$ and $\max_{otime}$ denote the minimum and maximum overflow time of all nodes. Nodes are assigned to clusters according to the following equation:

$$n_i \in C_j, \begin{cases} if 2^{j-1}\min_{otime} \le i_{otime} \le 2^j \min_{otime}, j = 1,2..N-1 \\ if 2^{j-1}\min_{otime} \le i_{otime} \le \max_{otime}, j = N \end{cases}$$

We define a cycle as a closed path among a set of nodes, such that no node is included more than once in the same cycle. We also define a supercycle as a closed path composed of concatenated cycles such that every node is included at least once in a supercycle. In our algorithm, a supercycle is equivalent to the period of the ME schedule.[13]

1) Sub-cluster Partitioning According to Locations

Each cluster obtained above is then partitioned into sub-clusters according to the node locations such that the nodes in the same sub-cluster are geographically close to each other. The number of sub-clusters of a cluster Cj is calculated based on the index j . The KD-tree algorithm is utilized to realize this partitioning. KD-tree is a k- dimensional binary search tree for information retrieval by associative searches. In our case, we use the 2D-tree where the two dimensions are the length and width of the sensor deployed field [13].

B. Fitness Function Estimation

In the basic Particle Swarm Optimization (PSO) model, a particle swarm stands for a bird flock and searches the solution in a D-dimensional real space. Each particle has its own position vector and velocity vector, which are both D-dimension. All the particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. The particles are "flown" through the problem space by following the current optimum particles.

Fitness is used to evaluate the performance of particles in the swarm. Generally, choosing a proper objective function as fitness function to represent the corresponding superiority of each particle is one of the key factors for successful resolution of the relevant problem using PSO algorithm.

The vehicle routing problem is a difficult combinatorial optimization problem, and generally can be described as follows: Data are to be delivered to a set of sensor nodes in each cluster by the mobile sink. The locations of the sensors and the clusters are given. The objective is to determine a viable route schedule which minimizes the distance or the total cost with the following constraints:

(1) Each sensor nodes is served exactly once by exactly one sink;
(2) Each sink starts and ends its route within a cluster;
(3) The total length of each route must not exceed the constraint;
(4) The total demand of any route must not exceed the capacity of the sink.

Therefore, we choose the following equation as fitness function:

$$f(x_i) = \sum_{i=1}^{N}\sum_{j=1}^{N} C_{ij} B_i B_j \quad (3)$$

Where N represents the number of nodes in a cluster, Cij is the cost of traveling from sensor i to sensor j by sink k . B_i and B_j are the buffer overflow times of sensors and respectively.

Then by substituting the fitness function (3) in to Algorithm-1, the particles are updated as per (1) and (2) and the best visiting path for the sink within a cluster is determined [13].

IV. Relay Node Deployment

A.Selection of Relay Nodes

Information is given to the distant nodes from beacons by overhearing. Since it is out of the communication range, information is not sent directly to static sink (SS). We propose

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that if a distant node is not able to communicate directly then it should send its own packet to another node which is closer to sink. Then the received packets are relayed to the sink by this node. Initially, each of the distant nodes chooses a relay node. The selection procedure is as follows:

- Each data packet of direct communication should include the received signal strength (RSS) of beacon packet, RSS_{beacon}.
- A distant node can overhear many transmissions from different nodes.
- The distant node selects a node with the maximum RSS_{beacon} value as a relay.
- When multiple nodes have the same, the nearest node is selected as a relay.

The data sent by a distant node is delivered in two steps:

(i) Node to relay
(ii) Relay to SS.

Relay-to- SS communication is similar to normal node-to-SS direct communication. The direct communication of other nodes should not be interrupted by the Node-to-relay communication. And so, when the SS is far from them, the distant nodes need to transmit to the relay. The proposed relaying operation resembles clustering as many distant nodes choose the same node as the relay. The node communicating with the SS is the cluster head. Cluster members are the nodes other than the cluster heads. Conversely, in the proposed scheme, there is no information to the cluster head about the cluster members and few cluster heads has no cluster members at all. In nature, clusters overlap

B. Efficient Assignment of Relaying Intervals

We propose to develop an effective algorithm for transmitting interval assignments to reduce the contention and improve energy efficiency. Time is divided into relaying intervals and each of this is consigned to a time interval. Each of the relaying intervals that transmitted a data packet in the corresponding time interval is assigned to a node. This node becomes the cluster head which holds the assigned relaying interval. At the assigned relaying interval, the distant node which decided to be a cluster member will start with the contention for transmission.

The proposed assignment algorithm is used for two reasons. For minimization of the listening time the algorithm wakes up the cluster head and the cluster members at the same time. Just before the assigned relaying interval, a cluster has to wake up and after all cluster members finish transmitting to the cluster head the cluster has to turn off. The other purpose is to distribute the contending nodes uniformly over time to minimize the number of concurrent contending nodes. This can also be done by spatially isolating the overlapping relaying intervals.

For the synchronized wake-up for all cluster members, every node should know which relaying interval is assigned to its own cluster. This can be calculated from which index of the time interval used for transmission of the cluster head. Let the cluster head use j-th time interval in i-th frame $(i = 1,2 \ldots Fn \text{ and } j = 1,2 \ldots Ts)$ for direct communication.

All cluster members also know values of i and j from the overheard packet. Using , and other parameters, such as

F_n –number of frames in a cycle,

T_s – number of time slot in frame,

F_1 –frame length,

T_c – length of control slot,

L_{beacon} – length of beacon slot

L_t – length of time slot,

L_r – length of relaying slot,

T_r – waiting time of relaying slot,

r - relaying-slot reuse factor.

The cluster head and all the members in the cluster can calculate the start time of the assigned relaying interval. The values of these parameters should be sent to nodes in a beacon packet or determined in advance. The start time of the assigned relaying interval st can be calculated as

$$st = stf + T_r + \left[(i-1)_{\text{mod}} \left[\frac{F_n}{2r} \right] * T_s + j - 1 \right] * L_r \qquad (4)$$

$$stf = c\,time - \left[(i-1)_{\text{mod}} \left[\frac{F_n}{2r} \right] * T_f + (j-1) * L_t + L_{beacon} + T_c \right] \qquad (5)$$

where ctime denotes the moment of time slot in which the data packet is transmitted to the BS.

If $r = 1$, no relaying interval is overlapped in time.

If $r > 1$, a relaying interval can be reused by r clusters

Since a relaying interval is reused, the length of relaying interval is k times larger than the length of time interval. As k increases, the length of relaying interval increases. For the reuse of relaying intervals, a cycle is divided into 2r fraction. The i^{th} frame belongs to the $\left\{ (\text{i-1})_{\text{mod}} \left[\frac{\text{F}_\text{n}}{\text{2r}} \right] + 1 \right\}$-th fraction. stf means the start time of the corresponding fraction. No time intervals in a fraction share the same relaying interval. At a glance, frame i shares relaying intervals with frame $i + \left[\frac{\text{F}_\text{n}}{\text{2r}} \right]$.

V. Combined algorithm

The steps involved in entire process are summarized in the following algorithm.

Algorithm-2

1. Let $SN_1, SN_2 \ldots SN_k$ be the number of mobile sinks and SN be a central static sink
2. Let $N_1, N_2 \ldots N_n$ be the total number of sensor nodes in the network.
3. Let $B_1, B_2 \ldots B_n$ be the buffer overflow times of sensor nodes $N_1, N_2 \ldots N_n$ respectively.

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4. Cluster all the sensor nodes according to the location and increasing order of the buffer overflow times.
5. For each cluster C_i , $i = 1,2\ldots r$
   5.1 Find the fitness function $f(x_i)$ using equation (3).
   5.2 Update the *pbest* and *gbest* values using the equations (1) and (2).
   5.3. If best path is found, then
   Break
   Else
   Repeat from step 5.
   End if.
   End for.
6. Let t_k be the time interval,
7. For each sink SN_j ,
   7.1. SN_j collects data from N_i in cluster C_j ,
   $i = 1,2\ldots n$
   7.2. SN_j send collected data to the centralized sink SN.
   7.3. If SN_j fails then
   7.3.1 It includes a RSS_{beacon} packet and transmit towards the sink.
   7.3.2 If the forwarding node not able to send directly to the sink,
   7.3.2 1 It selects a node with the maximum value as a relay node.
   7.3.2.2 Assign time interval to the relay node.
   7.3.2.3 Relay node transmits the data in its time interval.
   Else
   7.3.2.4 sends data directly to.
   End if
   End if.
   7.4.
   End for

VI. Simulation Results

A. Simulation Model and Parameters

We evaluate our PSO based Multi Objective Sink Repositioning Algorithm through NS2 simulation [15]. We use a bounded region of 1000 x 1000 sqm, in which we place nodes using a uniform distribution. We assign the power levels of the nodes such that the transmission range and the sensing range of the nodes are all 250 meters. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. The simulated traffic is Constant Bit Rate (CBR). The following table summarizes the simulation parameters used

No. of Nodes	20,40,60,80and 100
Area Size	1000 X 1000
Mac	802.11
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512
Transmit Power	0.360 w
Receiving Power	0.395 w
Idle Power	0.335 w
Initial Energy	5.1 J
Routing Protocol	EEDT
Speed	10 m/s

B. Performance Metrics

We compare the performance of our proposed Energy Efficient Data Transmission Algorithm (EEDT) with the Partition Based Scheduling (PBS) [14]. We evaluate mainly the performance according to the following metrics:

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Drop: It is the average number of packets dropped.

Average Packet Delivery Ratio: It is the ratio of the number of packets received successfully and the total number of packets sent.

Average Energy Consumption: The average energy consumed by the nodes in receiving and sending the packets.

C. Results

In our experiment, we vary the number of nodes as 20,40,60,80 and 100.

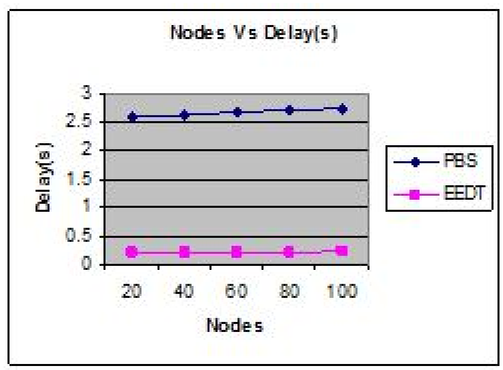

Figure1. Nodes Vs Delay

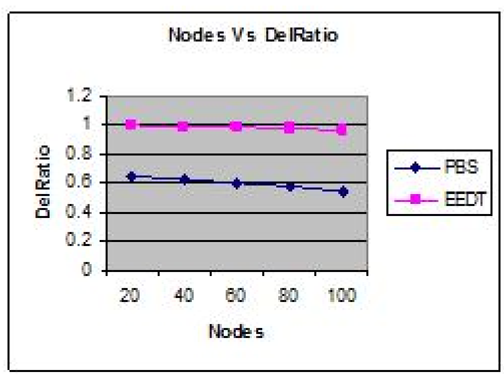

Figure2. Nodes Vs Delivery Ratio

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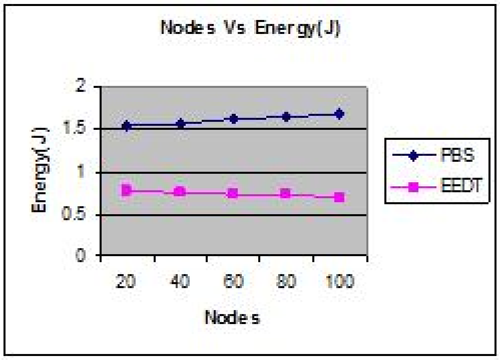

Figure 3. Nodes Vs Energy

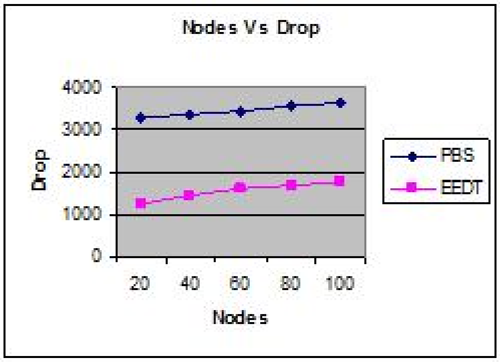

Figure 4. Nodes Vs Packet Drop

When the number of nodes is increased, the end-to-end delay is also increased, since the number of nodes to visit by the mobile sink is more. Since EEDT is hybrid (ie both have mobile and static sinks) data reaches faster to sink. From Figure 1, it is seen that the average end-to-end delay of the proposed EEDT protocol is less when compared with PBS.

When compared to PBS, EEDT is fault-tolerant as it can switch over to the static sink, in case of mobile sink failures. So the packet drop is less and packet delivery ratio is more for EEDT. From Figure 2, it is seen that the packets dropped are less for EEDT when compared with PBS. Figure 3 presents the packet delivery ratio of both the schemes. Since the packet drop is less, EEDT achieves good delivery ratio, compared to PBS.

Figure 4 shows the results of energy consumption. From the results, we can see that EEDT scheme uses less energy than PBS scheme, since it has energy efficient routing.

VII. Conclusion

In this paper, we have proposed a relay node selection algorithm in order to lessen the contention and improve energy efficiency. Information is given to the distant nodes from beacons by overhearing. Since it is out of the communication range information is not sent directly to static sink (SS). We have proposed that if a distant node is not able to communicate directly then it should send its own packet to another node which is closer to BS. Then the received packets are relayed to the BS by this node. Initially, each of the distant nodes chooses a relay node. The selection procedure is estimated. Time is divided into relaying slots and each of this is consigned to a time slot. Each of the relaying slots that transmitted a data packet in the corresponding time slot is assigned to a node. This node becomes the cluster head which holds the assigned relaying slot. At the assigned relaying slot the distant node which decided to be a cluster member will start with the contention for transmission. By the simulation results we have shown that this algorithm improves energy efficiency and packet delivery ratio compared to the Partitioned based Scheduling Method.

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